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Remote Sensing in the Ultraviolet

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UNITED STATES AIR FORCE  
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## REMOTE SENSING IN THE ULTRA-VIOLET

### 1. INTRODUCTION

This research program on remote sensing in the ultraviolet has been primarily devoted toward development of imaging spectrophotometers sensitive in the ultraviolet and suitable for satellite borne applications. In addition, a significant amount of effort was devoted to supporting ground based UV measurements of rocket exhaust signatures and in redesigning and configuring one of AFGL's existing ground based UV imaging system for wide field of view observations of the aurora in the near UV.

Two technical papers, written and published during this contract, cover important portions of the work accomplished under this contract. The first paper reports on the spatial resolution of proximity focused image intensifier tubes as a function of photon energy.<sup>(1)</sup> The second paper reports on the development of a special micro channel plate (MCP) tube employing magnetic focus between the photocathode and the MCP.<sup>(2)</sup>

The two space borne imaging applications studied were (a) UV background measurements with a spatial resolution of 100 meters and (b) aurorae photometric measurements at a spatial resolution of 1 to 2 km. The parameters relevant to these two applications are listed in Table I.



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Table 1

A. Measurement of ultraviolet background seen by earth looking satellite.

Requirements:	Spatial resolution	100 m
	Temporal resolution	orbit period*
	Swath width	dependent variable (~50 km)
	Spectral Range	1250-3200 Å
	Spectral resolution	200 Å
	Threshold sensitivity	10 Rayleigh in 200 Å band
	Dynamic range	$10^4$
	Intra- scene dynamic range	$10^2$
	Altitude	1000 km
	Orbit	polar

B. Observation of Aurorae from Satellites

Requirements:	Spatial resolution	~1 to 2 km for Aurorae
	Temporal resolution	~1 second
	Swath width	400 km or greater
	Spectral range	1200 to 3000 Å
	Spectral resolution	50 Å
	Threshold sensitivity	10 Rayleigh Å <sup>-1</sup>
	Dynamic range	$\sim 10^3$
	Intra- scene dynamic range	$\sim 10^3$
	Altitude	1000 km
	Orbit	polar

-----  
\*Pictures of the same spot on the earth are obtained every few days depending on the satellite orbit. The exposure time is selectable up to  $nw/S_v$  where n is the number of pixels employed in time delay integration, w is the pixel height and  $S_v$  is the satellite velocity.

The Space Test Program Flight Request, Experiment No. AFGL-702 Atmospheric Ultraviolet Radiance Analyzer (AURA) is directed toward measurement of the earth's ultraviolet background as seen from an earth orbiting satellite, i.e. the first application summarized in Table 1. The following discussion on "Imaging the Earth from Satellites" provides further detail on parametric tradeoffs used during the course of this research to develop a flight instrument.

## 2. ON IMAGING THE EARTH FROM SATELLITES

### 2.1 Pixel Rate

A satellite borne imaging system with a cross track field of view  $\theta$  has a mapping rate equal to the product of the satellite's ground track velocity,  $S_v$  times  $h\theta$  where "h" is the satellite altitude. The spatial image pixel rate, assuming square pixels of width  $w$  is:

$$\frac{h\theta S_v}{w^2} \text{ pixels per second} \quad (1)$$

Digitizing the image for analysis and or transmission requires that each pixel of interest be sampled at least twice in each of its two dimensions to minimize the spatial filtering and aliasing associated with the sampling process. This is referred to as the Nyquist limit. This means that in practice, the digitized pixel rate is 4 times the basic number given by equation (1).

It should be noted that the digitized pixel, defined in this case as one half the width of the pixel of interest from an analysis standpoint, is usually the pixel used in most system descriptions of digitized imaging systems. The more rigorous definition used in this discussion is invoked to indicate more nearly the actual spatial resolution that is achieved at a useful spatial frequency response (MTF) at the output of the digital imager system.

### 2.2 Exposure Time

To limit the image smear due to motion of the satellite along the orbit, the exposure time,  $\Delta t$ , for a framing camera employing a shutter, is limited to approximately one fourth the ground resolution of interest divided by the satellite velocity. This same condition applies to an unshuttered line array that integrates the exposure for one line period.

$$\Delta t = \frac{w}{4S_v} \quad (2)$$

This 1/4 pixel motion during the exposure time results in 10% reduction in the MTF of the imaging system due to image motion. At the same time it more than satisfies the Nyquist limit of two samples along the track for each ground resolution pixel of interest.

### 2.3 Optical Exposure

The number of photons per picture element imaged by an optical system is:

$$\frac{E D^2}{4} \Delta t T \left(\frac{w}{h}\right)^2 \quad (3)$$

Where "E" is the scene illuminance in photons per second per unit area per steradian and "D" is the diameter of the optical collecting aperture.

$\Delta t$  = exposure time

T = optical efficiency.

Substituting for the exposure time,

$$N = \frac{E D^2 T w^3}{16 h^2 S_v} \text{ photons per pixel per exposure.} \quad (4)$$

As discussed above, the pixel should be sampled twice in the cross track direction, such that the number of photons per sample is actually:

$$N = \frac{E D^2 T w^3}{32 h^2 S_v} \text{ photons per digitized pixel.} \quad (5)$$

### 2.4 Satellite Ground Track Velocity, $S_v$

A satellite's orbit period is given by the equation

$$\text{Orbit Period} = 84.6 \left( \frac{a}{R_E} \right)^{3/2} \text{ minutes} \quad (6)$$

where  $R_E$  is the Earth's radius and "a" is the semi-major axis of the elliptical orbit.

For a 1000 km altitude circular orbit the orbit period is 105.26 minutes. The satellite's ground track velocity  $S_v$  is the Earth's circumference divided by the orbit period

$$S_v = \frac{2\pi R_E}{84.6 \left( \frac{R_E + h}{R_E} \right)^{3/2}} \quad (7)$$

$$R_E = 6378.5 \text{ km,}$$



$$S_v = \frac{4.022 \times 10^6}{(6378.5+h)^{3/2}} \text{ km/sec}$$

For  $h = 1000 \text{ km}$ ,  $S_v = 6.35 \text{ km/sec}$

## 2.5 Optical Exposure vs Ground Resolution

Returning to equation (5), let

$h = 1000 \text{ km}$

$T = 0.25$  including filter transmission

$Q_e =$  detector quantum efficiency = 0.16

$D = 25 \text{ cm}$

$E =$  expressed in Rayleighs,  $R = \frac{10^6}{4\pi} \text{ photons cm}^{-2} \text{ sec}^{-1} \text{ steradian}^{-1}$

$$N = \frac{(E \times 10^6) (25)^2 (0.25) (0.16) w^3}{4\pi (32) (10^3)^2 (6.35)}$$

$$N = E w^3 \times 10^{-2} \text{ photoelectrons pixel}^{-1} \text{ Rayleigh}^{-1} \quad (8)$$

$w$  is in units of km

Figure 1 is a graph of equation (8) showing the pixel exposure  $N$  as a function of  $w$  for a range of scene radiance values  $E$ . It is clear from Figure 1 that the exposure time and or the optical aperture needs to be increased in order to reach the threshold sensitivity listed in Table 1.

## 2.6 Image Motion Compensation

For a given ground resolution and satellite orbit the exposure per pixel  $N$  can be increased by increasing the optical collecting aperture. This, of course, increases the payload size, weight, and cost. Alternatively, image motion compensation can be employed to extend the exposure time. In aerial photography, photographic film, is moved across the focal plane at a rate that matches the image motion due to the airplane's lateral motion relative to the earth, or the film is held fixed and a mirror in the optical path rotates to hold the image fixed during the exposure time.

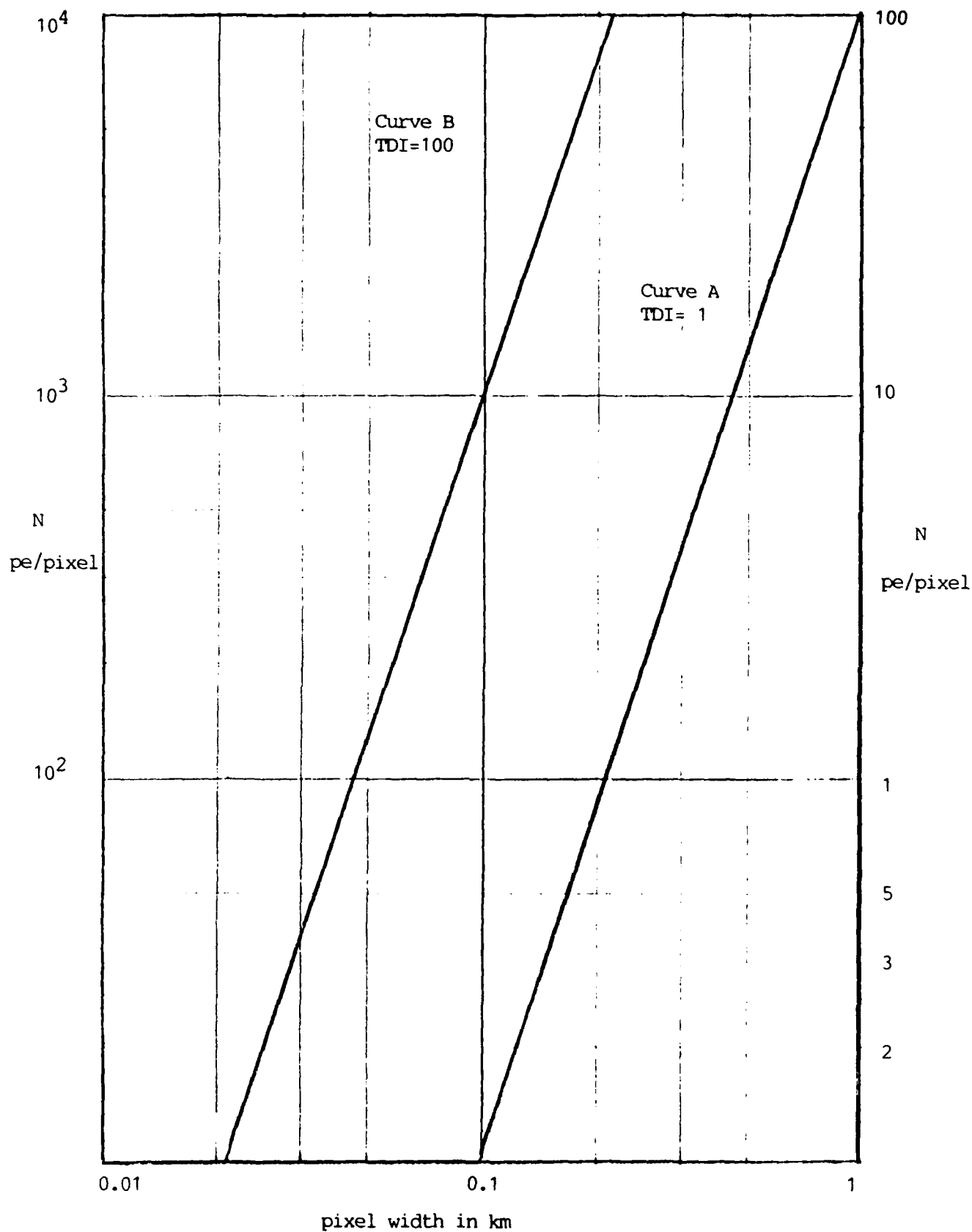


Figure 1--- Graph showing pixel exposure N as a function of ground resolution "w" for a scene radiance "E" of 10 kiloRayleigh. Curve A has a time delay integration period of 1 pixel dwell time and Curve B has a time delay integration of 100 pixel dwell times.

Image motion compensation can be implemented without physical motion by two schemes of interest for the UV imaging spectrophotometer.

- a) The photoelectrons from an image tube photocathode can be deflected at a rate that fixes the image on the anode, i.e. analogous to the rotating mirror.
- b) The electrical charge pattern in a CCD can be shifted at the same rate to make an analog of moving the photographic film across the focal plane.

Both of these techniques seem applicable to extending the exposure time in a satellite borne camera system and can be employed in combination. For example, the CCD charge shifting can be used to compensate for the predictable image motion due to the satellite orbital motion and electronic deflection in the image tube can be used to compensate for any pitch and roll angular motion of the satellite, provided angular error signals are available from internal references or star trackers. The electronic deflection also provides the facility to smooth out the image motion compensation steps inherent in shifting the charge from one discrete line to the next in the CCD.

The CCD on the other hand relieves the electronic deflection from having to make large correction to the image position which can lead to geometric distortion of the image.

## 2.7 Yaw Correction

Yaw of the satellite relative to its ground track causes the optical image to traverse the focal plane at an angle. Time delay integration in such case causes the optical image to be smeared, depending on the amount of yaw and the number of lines that are integrated together. For example, if full advantage were taken of the TD1 process in a 512x512 pixel CCD, then one would want the optical image to be aligned all the way down the 512 lines of the CCD. A one pixel yaw, corresponding to an angle of  $1/512$  radian ( $\approx 0.1$  degree), would significantly degrade the spatial resolution in the cross track direction.

The electron optics in a magnetically focused image tube can, under certain circumstances, rotate the image, usually an aberration to be avoided. In this application it affords an opportunity to correct for yaw electronically and not have to implement remote

mechanical rotation of the CCD in the yaw plane in the satellite. Such electronic rotation is accompanied by some magnification or demagnification of the image in the electron optics. This facility to correct for yaw and thereby extend the exposure time without loss of spatial resolution is an exciting prospect that has been explored in detail in this research contract. It should be noted that to correct for yaw, it must first be detected. This may require dithering the electronic yaw correction to find the setting that provides the finest spatial structure in the recorded image.

It is clear from the foregoing systems analysis that image motion compensation is necessary to obtaining high spatial resolution images of the earth in the ultraviolet from a satellite borne camera system of realistic optical aperture. Both CCD time delay integration and image deflection/rotation in an image tube are promising techniques to be pursued toward defining a prototype image sensor for UV imaging from a satellite.

## 2.8 Optical Considerations

The focal plane image scale is determined by the optic focal length  $F$ :

$$\frac{w'}{F} = \frac{w}{h} \quad (8)$$

where  $w'$  is the pixel size in the instrument focal plane. The optical aperture diameter  $D$  is related to the focal length by the  $f$  - number of the optical system

$$f/\# = \frac{F}{D} \quad \text{and} \quad \text{In practice, } \frac{F}{D} > 1 \quad (9)$$

Therefore for a given angular resolution the larger the detector pixel the longer the focal length and the larger the optical aperture is allowed to be. And conversely, shorter focal lengths require smaller detector pixels for a given ground resolution  $w$ .

Following this line of reasoning, changing from a 25 to 40 mm diameter image tube affords the possibility of increasing the optical collection by a factor of 2.56 at the same  $f$ -number.

A larger diameter image tube also lowers the operating spatial frequency and thereby improves the spatial frequency response of the image tube. It is in the direction to improve the optical MTF also, but it is less clear how much it is improved, depending on the particular telescope, etc. Alternatively the larger diameter makes it reasonable to increase the number of pixels across the image, while at least maintaining the image tube MTF. For example, replacing the 25 mm tube with a 40 mm tube allows a 60% increase in the number of pixels or a 40% reduction in the spatial frequency for the same number of pixels across the image. One does not have to stop at 40 mm but the price of the tube and things like filters increase significantly above 40 mm. The optical coupling efficiency between the output of the image tube and the television camera is expressed by the following equation,

$$\frac{1}{4F^2(1 + \frac{1}{m})^2}$$

when F is the focal ratio and m is the ratio of image size to object size. So, for a fixed image size on the CCD, a larger image on the output of the image intensifier results in lower optical coupling efficiency which must be made up by higher intensifier gain if one is to maintain the higher sensitivity gained in the first place by increasing the image tube diameter. This qualitative argument is true for both lens and fiber optic coupling, (but the fiber optic is more efficient to begin with).

## 2.9 Optics

The optical requirements for the two missions are considerably different and it appears that the optimum optical system will be different in the two cases. Assuming a 45 mm diameter photocathode (10% demagnification in the electro optics), and a 500x500 pixel circumscribed square format, the optical pixel width is ~ 63 microns. Referring to Table 1, for aurorae observations, the spatial resolution requirement is 1 to 2 Km. 1 Km resolution at a satellite altitude of 1000 Km corresponds to an angle of  $10^{-3}$  radian and an optical focal length of 63 mm. The angular field of view is 0.5 radian wide and 0.7 radian on the diagonal.

For ultraviolet background measurements the spatial resolution of interest is an order of magnitude finer, 0.1 Km and the optical focal length is correspondingly 630 mm. The diagonal field of view is 0.07 radian or 4 angular degrees.

Relatively conventional reflective telescope optics can be employed for the 4 degree field of view case. A 40° field of view, while maintaining a flat focal plane, is more challenging.

### 3. IMAGE INTENSIFIER DEVELOPMENT

There is a strong argument for utilizing a solar blind magnetically focused image intensifier coupled to a CCD type image sensor. Figure 2 shows four concepts for the UV image sensor.

- A. Magnetically focused image intensifier fiber-optically coupled to a MCP image intensifier and then lens or fiber optically coupled to a CCD.

The disadvantage of this combination is the loss of resolution in the proximity focused photocathode.

- B. Magnetically focused MCP image intensifier, lens or fiber optically coupled to a CCD.

The disadvantage of this is that it is a special tube but not much more difficult to build than a proximity focused MCP tube.

- C. Magnetically focused image tube in which the CCD replaces the phosphor.

Disadvantage is that it is a special tube requiring a special electron bombardable CCD.

- D. Magnetically focused image intensifier fiber optically coupled to a CCD.

Disadvantage is that the tube is special and the net gain of this combination is relatively low.

Also difficult to cool the CCD without cooling whole tube.

These concepts were discussed during the June 17, 1988, meeting at AFGL and it was mutually agreed that B, the magnetically focused MCP tube, was the most promising approach, given all of the factors involved. An order was subsequently placed with ITT for a tube shown in Figure 2 having the following characteristics:

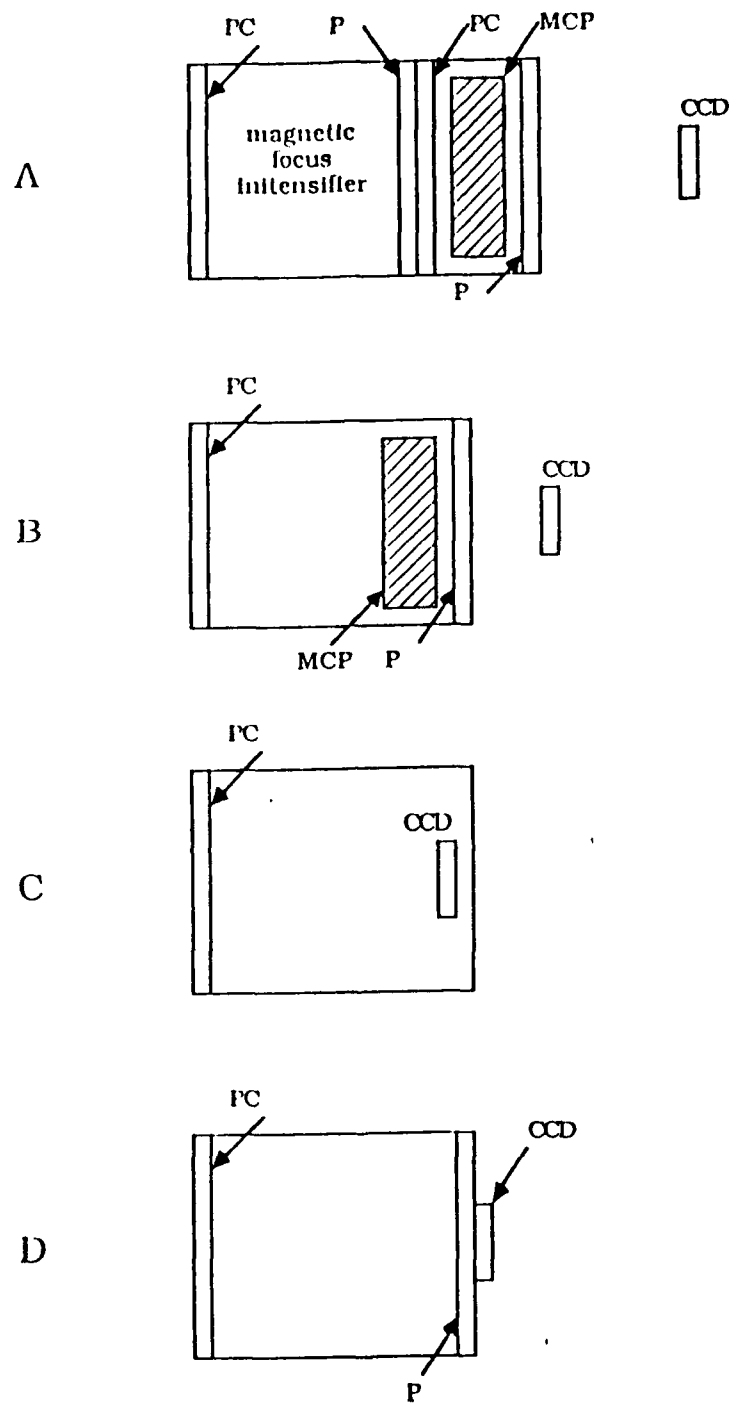


Figure 2--- Four concepts for Ultraviolet image sensor.  
See test for descriptions.

Photocathode	-	bi-alkali on $MgF_2$ window
MCP	-	40 mm diameter, 12 micron pitch 10 micron pores, 40 to 1 L/D ratio
Photocathode to MCP distance	-	100 mm
Phosphor	-	P20 on fiber optic

The tube is a combination of a standard 40 mm proximity focused MCP tube and a magnetic focus image intensifier that has been made for NASA. Utilizing these standard components reduces the cost and delivery and probably also improves the probability of getting a good tube.

A bi-alkali photocathode was chosen to allow the tube to be used in near term ground based applications, while still serving the primary function of laboratory testing of the image sensor concept and the yaw correction related to time delay integration with the CCD.

#### 4. ELECTRONIC IMAGE ROTATION - YAW CORRECTION

As discussed in section 2, magnetic focusing can be used to rotate the image between the photocathode and anode in an image intensifier tube. In general, the rotation is induced by a flaring or concentration of the magnetic field such as that which exists near the end of a solenoid. A computer program that calculates the trajectory of electrons in an electromagnetic field has been employed to study this phenomena relative to the image intensifier being built for this study.

Figure 3 shows the solenoid consisting of two separate windings and the magnetic field for four different cases. The ratio of the electrical current in the two coils is varied to change the shape of the magnetic field near the mouth of the solenoid. The resultant rotation is shown in Figure 4 for the four discrete solenoid current settings shown in Figure 3. Rotation is accompanied by demagnification or magnification of the image. In this example the magnetic field is stronger at the anode than at the photocathode, resulting in demagnification, as the electrons tend to follow the field lines.



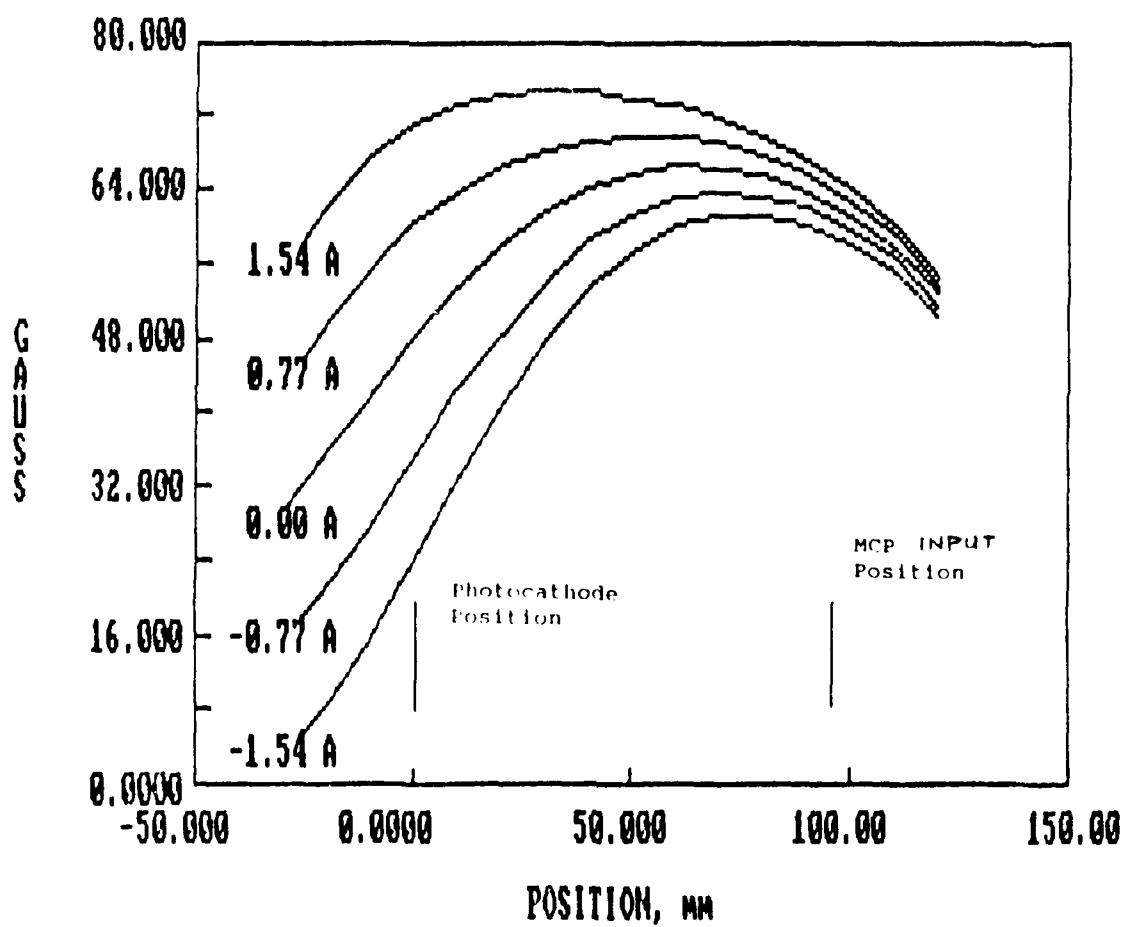


Figure 3-- Graph of solenoid magnetic field used to focus the magnetically focused MCP tube showing the location of photocathode and MCP input face.

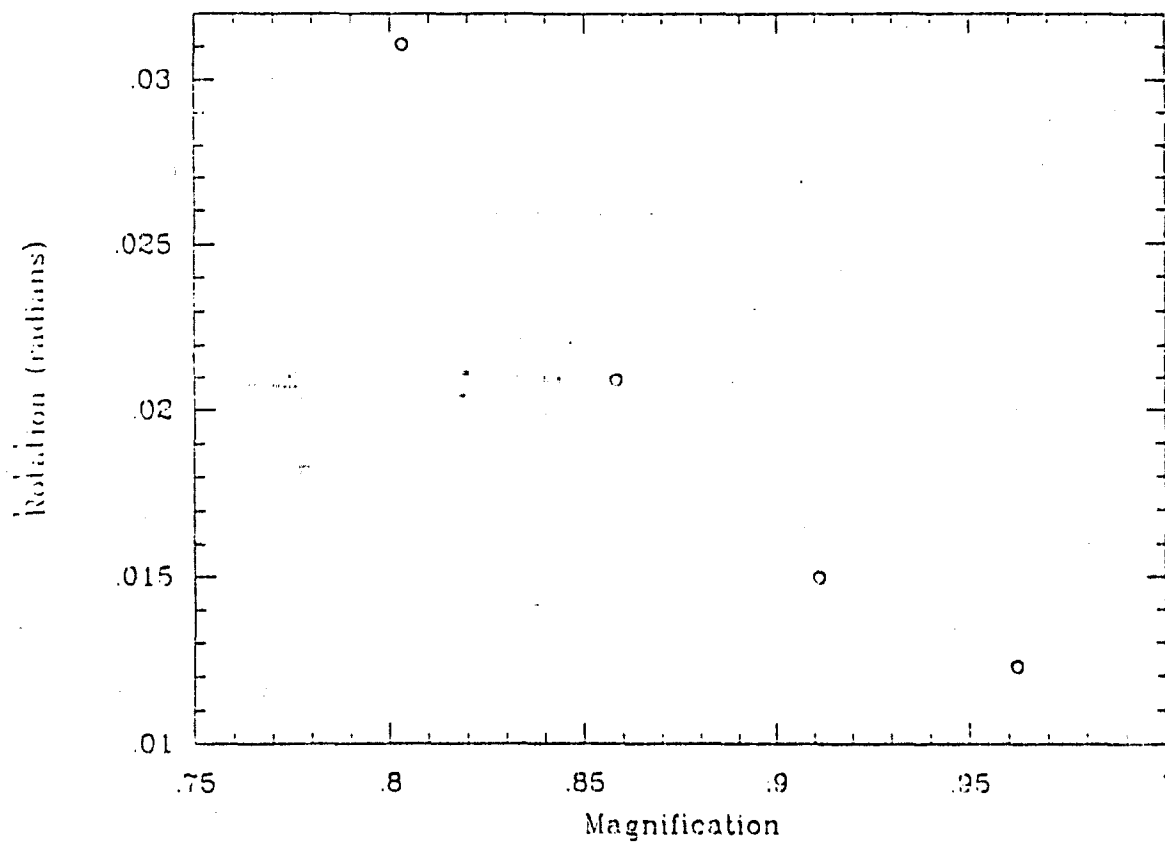


Figure 4--- Graph of image rotation and magnification changes for magnetic fields shown in Fig. 3.

In the proposed application the image tube would be set up to operate with a nominal image rotation of perhaps 0.015 radian (52 arc minutes). This corresponds to an image magnification of 0.9. A yaw correction of 52 arc minutes can be made in one direction and an arbitrarily larger correction would be possible in the other direction.

## 5. YAW ERROR DETECTION

The time delay integration mode of operating a CCD type solid state image sensor is a means of image motion compensation that allows the exposure time to be significantly extended. It requires that the direction of motion of the camera and the vertical columns in the CCD are parallel, such that the electrical charge image in the CCD move in exactly the same direction as the optical image. The uncertain spatial detail in the aurora makes it difficult if not impossible to assess any smearing resulting from yaw between the image motion and the CCD columns.

A more suitable means of detecting yaw appears to be to observe stars which, being point sources, have known spatial characteristics. In order to use the stars for detecting yaw, a star field can be imaged onto at least a portion of the CCD's image sensitive area and could be superimposed onto the image of the earth/aurora.

The stellar image motion is in the same direction as the earth image motion. However, the rate is different in the two cases. From a 1000 km orbit the ground track rate of motion is 6.35 km per second. And for the 0.1 km pixel case this corresponds to 63.5 pixels per second.

The orbit period corresponding to a 1000 km orbit is 6,316 seconds and the angular rate of motion of the satellite around the earth is 0.001 radian per second, corresponding to 10 pixels per second in this case where 0.1 km on the earth viewed from 1000 km altitude corresponds to 0.0001 radian.

The relative motion of the star field and ground track is  $63.5 - 10 = 53.5$  pixels per second, resulting in an exposure time of 0.019 seconds per pixel for the stars.

The stellar images will appear as vertical streaks. Just how vertical is a measure of the yaw. A given star will appear on  $50 \times 63.5 = 3175$  pixels as it enters and leaves the field of view of the camera. This should allow yaw to be measured to at least  $3175/2$  assuming that the

star moves from one pixel to the next during the time it is in view. This accuracy is more than enough for correcting the ground track yaw since the exposure time for the earth image is 500 pixels long.

The stellar images represent an impulse function to the system that allow its overall spacial frequency response to be measured. This makes it possible to correct the yaw related smearing of the image as a part of the ground based data reduction process. This has the appeal of making the orbiting instrument less complicated. Such amplification of the high spatial frequency components, "peaking", has the disadvantage of lowering the signal to noise ratio since the noise is also amplified.

For this reason it is generally better to eliminate the yaw related smearing by eliminating the yaw itself.

Such yaw correction requires maintaining the satellite orientation such that the CCD's vertical columns are aligned with the optical image of the ground track of the satellite or by rotating the image of the ground track incident on the CCD to achieve this alignment.

#### 5.1 Closed Loop Yaw Correction

It is interesting to consider a closed loop servo system to correct for yaw within the high resolution camera instrument itself.

By adding the video signal from successive lines together, any vertical structure in the image is enhanced. A relatively simple algorithm could identify stars against a background and measure the width of the star image in a summation of a large number of horizontal lines. This width would be proportional to the yaw and the direction of the yaw would be indicated by the direction of the drift in the centroid of the star image from top to bottom of the CCD. The detected yaw error would be integrated to control some form of rotator that would rotate the image relative to the CCD bringing the yaw error to zero.

Three methods for rotating the image have been identified:

1. Feed the yaw error signal to the spacecraft orientation control. This may not be acceptable, depending on the spacecraft mission and the other payloads onboard and it complicates the AURA payloads interface with the spacecraft.
2. Rotate the CCD with some sort of stepper motor driven turntable. This is technically straightforward, but does involve a mechanical mechanism in the space environment.
3. Electronic rotation of the image. This requires a magnetically focused image intensifier tube and a stable but controllable magnetic focus field.

At this time all three schemes are considered possibilities. Electronic rotation is the most novel and has been reduced to practice in a laboratory breadboard system.<sup>(2)</sup>

## 5.2 Optical Considerations

The ultraviolet imaging system's primary function is to obtain narrow band ultraviolet images of the aurora and any other ultraviolet features of the earth's atmosphere. Imaging the star field through these same narrow band optical filters is undesirable because it markedly reduces the number of star photons reaching the image sensor and thereby reduces the number of stars that can be used for deducing the yaw error. To configure the optics to allow the star image to bypass the optical filter, one must employ separate imaging optics for the stars and the earth. This opens up the opportunity to select a different focal length for the two cases and a correspondingly different field of view, at the expense of providing an optical path behind the narrow band filter which could be a source of unfiltered scattered light in addition to the star images of interest.

Figure 5 is a schematic of one optical configuration showing the star field reflected off the back of the narrow band optical filter and onto the image sensor.

Figure 6 shows a second optical configuration in which the optics are preceded by a gimbaled mirror that allows the camera to view the earth, earth limb, or the sky. This configuration is particularly attractive because it affords the opportunity to use stars to calibrate the camera and to monitor any changes in the optical performance over time by viewing the same star field periodically throughout the life of the payload. This configuration

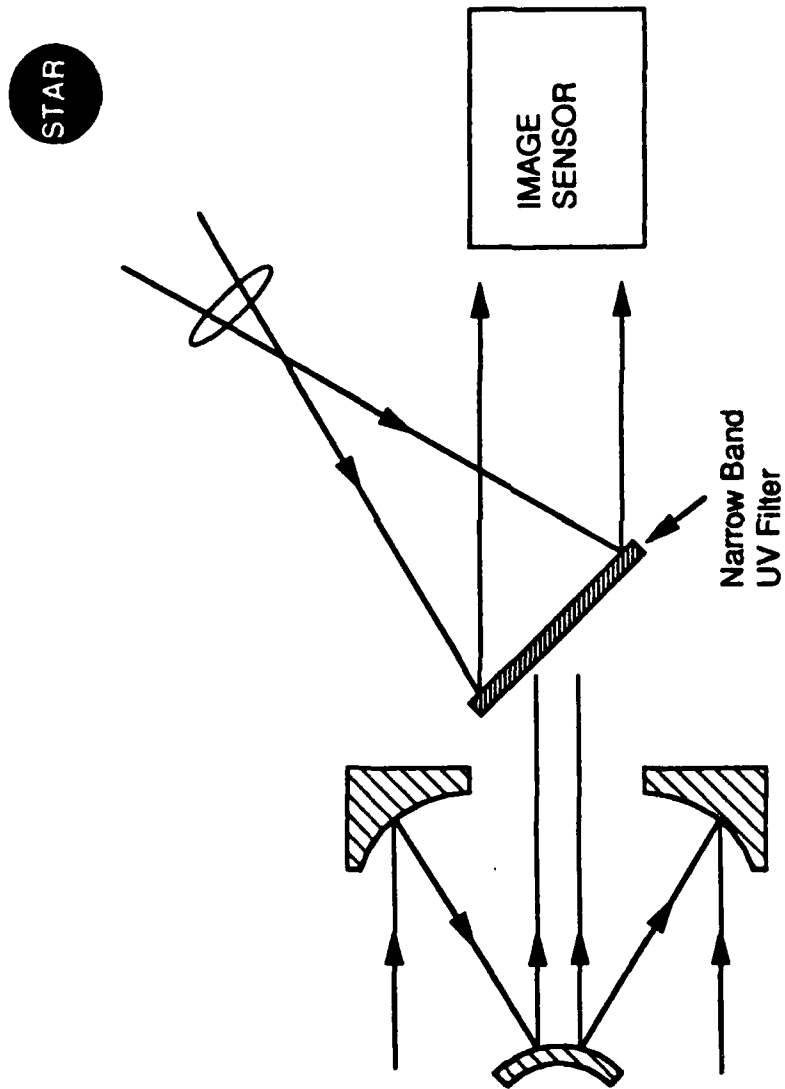


FIGURE 5 OPTIC CONFIGURATION FOR  
SUPERIMPOSING STAR FIELD ON IMAGE OF  
EARTH THROUGH NARROW BAND FILTER

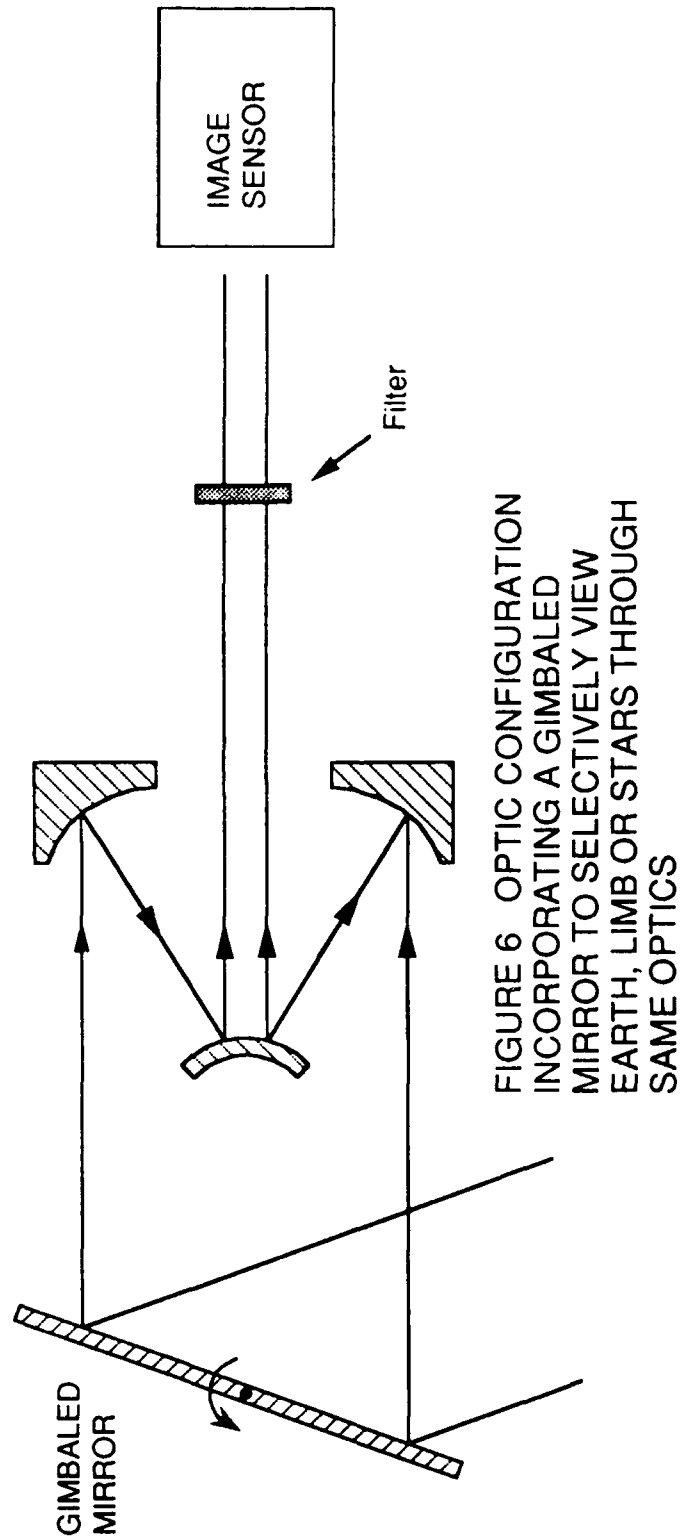


FIGURE 6 OPTIC CONFIGURATION  
INCORPORATING A GIMBALED  
MIRROR TO SELECTIVELY VIEW  
EARTH, LIMB OR STARS THROUGH  
SAME OPTICS

would allow periodic checks of yaw but the number of stars would be reduced unless the narrow optical bandwidth filter wheel is indexed to a position where there is a broadband filter or no filter at all.

As noted elsewhere, a gimbaled mirror could be used to extend the synoptic coverage of a particular region as well. This is important in operating the high resolution camera in concert with an on board radio beacon that is tracked by an antenna at a fixed site on the earth.

## 6. TEMPORAL RESPONSE OPTIONS

The time delay integration feature of the proposed system allows a maximum exposure time equal to the number of lines in the CCD times the pixel height divided by the satellite velocity.

$$\Delta t = \frac{nw}{S_v}$$

This works out to be 7.87 seconds for 100 meter pixel resolution, 1000 km orbit, and 500 horizontal line CCD. The minimum exposure time can be controlled by electronically shuttering the image intensifier. The exposure can also be controlled in certain CCD configurations that have a storage register. In such cases the electric charge accumulated during the exposure is rapidly shifted into the storage area and then read out in the normal fashion.

This facility to take short exposures in which the time delay integration is employed for fewer than the total number of lines in the CCD makes it possible to take a time series of images of the same region to explore rapid fluctuations in the temporal characteristics of the aurora. The temporal span of the series of exposures is, of course, limited by the time that the region remains in the field of view of the optical system. In the above case, this would be 6.35 seconds. Six 1 second exposures could be made, for example, providing aurora image data with temporal resolution of 1 second instead of 6.35 seconds. The exposure is reduced by the same factor of 6.35. It should also be noted that the pixel readout rate is correspondingly increased by a factor of 6.35. This is not a problem at the CCD readout rates being considered for the camera. Such a series of rapid exposures and readouts would need to be accommodated in the on-board digital



data storage subsystem.

## 7. DATA ACQUISITION/STORAGE REQUIREMENTS

The normal time delay integration mode operation corresponds to an average pixel rate of approximately 36,000 pixels per second (100 meter resolution, 500x500 pixel CCD). Images taken 1 second apart would increase the rate to 250,000 pixels per second. The on-board memory requirement of the high resolution camera are dependent on the mission and the frequency of access to ground stations for dumping the data. A 1000 km pass over the pole would take approximately 140 seconds and collect 5 million pixels of data. A pixel can be encoded into 8 bits so the on-board memory in this case would need a capacity of 5 mega bites plus the memory requirements of the other payloads and the satellite. This is a relatively modest memory by today's standards. Taking images at one second intervals over the same 1000 km segment of the orbit would increase the memory to 36 million bites, still a reasonable requirement.

## 8. AURA CAMERA SYSTEM DESIGN REQUIREMENTS

The conceptual design of the high resolution camera must consider the following requirements and ground rules:

- Digital encoding: 8 to 12 bits/pixel, selectable by ground command.
- Time delay integration clocking in vertical direction with ground control of clocking rate to microsecond precision.
- Normal mode of operation is continuous readout of lines as satellite orbits the earth.
- Exposure time controllable from the ground with provision for TDI exposures less than the total number of CCD lines.
- Pixels may be read out in a burst mode from a given line.
- Design for up to 1000 pixels per line, but camera more likely to have 512 plus overscan.
- Probably 512 lines in a TDI exposure.

- Line rate is a function of desired ground resolution, but is likely to be in the order of 15 milliseconds per line for 100 meter ground resolution, and for 500 pixels per line this works out to be a minimum average pixel readout time of approximately 30 microseconds.
- The satellite will not be dedicated to this mission so power and weight should be minimized without going to extremes.
- The video gain should be adjustable from the ground, perhaps three values.
- Desirable to be able to load the CCD clocking pattern from the ground to handle degradation due to radiation, power supply drift, etc.
- Focus coil power supply must be precisely adjusted, two supplies required for two separate coils unless one coil is replaced by permanent magnet. Not clear this is desirable or feasible without more study.
- Design for trapped radiation at 1000 km orbit.
- Provide ground control of HV power supply voltages.
- Design for this specific mission with programmability to accommodate degradation and failures in the camera.

## 9. GROUND BASED UV IMAGER SYSTEMS

### 9.1 AEDC Test Preparation of AFGL UV Imager No. 1

A series of rocket plume observations at AEDC involved a rocket nozzle 58 inches wide, approximately 25 feet from a 4 inch diameter viewing window. The required angular field of view was approximately 12 degrees. The AFGL UV Imager employs a 25 mm photocathode somewhat vignetted by the filter holder. The television camera has a 3x4 aspect ratio such that the picture width on the photocathode should be about 20 mm. For a 12° FOV the focal length needs to be 103 mm or less. A 90 mm Cassegrain type telescope was ordered from Nye Optical Company. This f/1.1 optical system has a back working distance of only 19 mm and the resolution off axis falls off. However, it was available and the AEDC application did not require high spatial resolution as much as it did high light collection efficiency.

Using this lens required building a filter wheel and filters that are no more than 0.5 inch thick. The new filter wheel was designed to be more reliable than the original one manufactured by Oriel, which wasn't designed for the operating modes it has been called to undertake in the UV imager, i.e. continuous cycling. The new design employs optical encoding of the wheel position and the wheel is driven by a stepper motor through planetary gears rather than the DC motor and belt configurations in the Oriel filter wheel.

UV Imager No 1 was also modified to facilitate remote control of the system from the block house.

## 9.2 Auroral UV Imaging/UV Image No. 2 Redesign

The AFGL "Vandenberg" UV Imager System was redesigned to more nearly meet the observing requirements for observing the aurora from the ground in the UV spectral band between 300 nm where the atmosphere begins to transmit out to about 400 nm. The redesign involved replacing the Fairchild CCD camera with a camera made by Patterson Electronics. This is a repackaged Sony CCD camera having a multi stage thermoelectric cooler to reduce the CCD dark current so that the exposure time can be extended to several seconds. A Nye Optical 65 mm catadioptric lens was installed in front of the image tube and preceded by a new filter wheel with two inch diameter filters. This reconfiguration, shown in Figure 7, was necessary to accommodate the short focal length of this lens. The two inch filter, six position filter wheel is larger than the filter wheel in the existing UV Imager. The thermoelectrically cooled CCD camera is also larger than the existing CCD camera. This required redesign of the enclosure, including elevating the optical axis to 3.69 inches above the mounting surface of the UV Imager head.

9.2.1 Filter Wheel In order not to vignette the optical input, the optical filter aperture must be 1.8 inches diameter. A new filter wheel was designed and built that takes 2 inch diameter filters up to 1 cm thick. It employs a geneva gear mechanism driven by a DC motor and there are optical sensors for each of the 6 filter positions. The geneva gear action results in the gear rapidly moving to the next position and then pausing. This helps insure the alignment of the

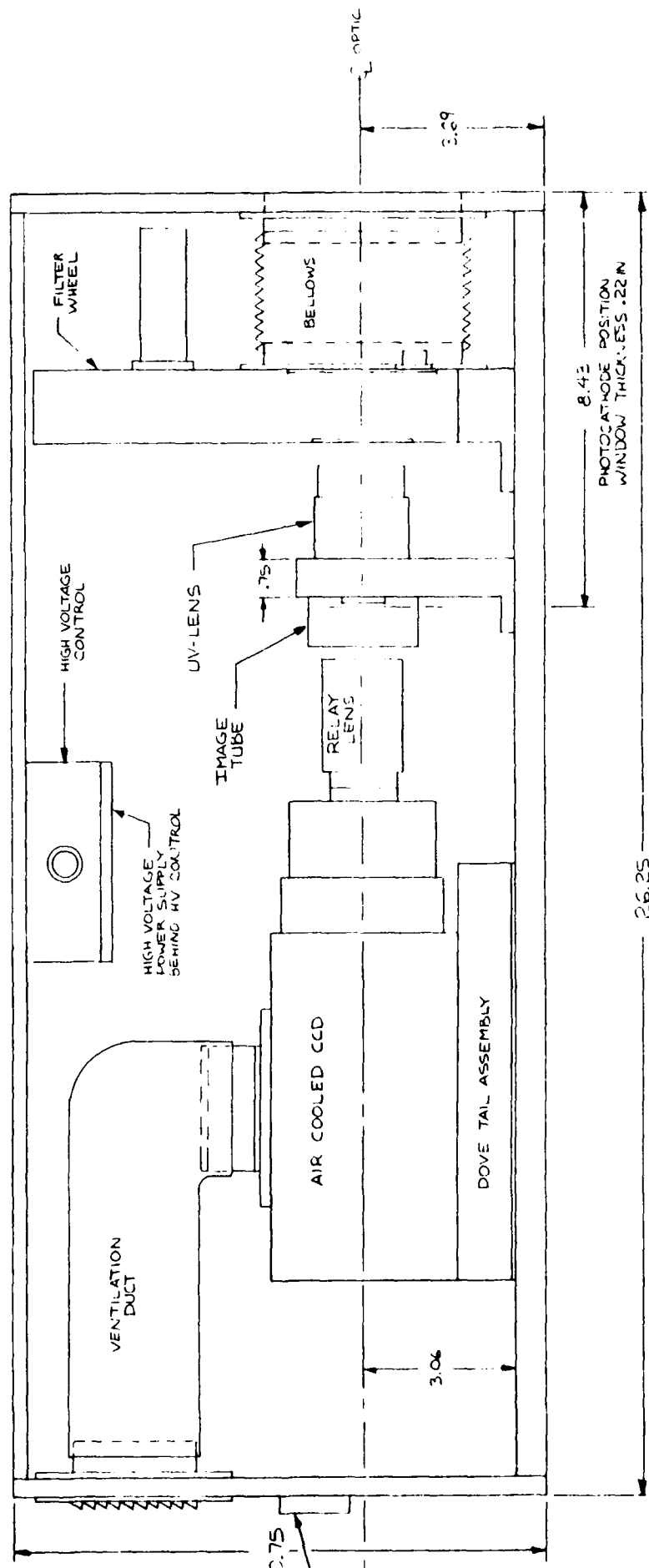


Figure 7--- Layout of UV Imager No. 2 configured for aurora observations.

filter with the optical axis and also increases the number of useful frames of data when the wheel is operated in the continuously rotating mode. Equally important in the mechanism is a direct drive, with no belts, and we believe it will prove to be easier to adjust and more reliable than the existing remotely controlled filter wheels.

#### 10. CONCLUDING REMARKS AND ACKNOWLEDGEMENTS

The analysis carried out under this BAA contract of the problem of making high resolution images of the earth from an orbiting platform has provided a clear understanding of the parametric relationships and the design constraints for the AURA mission. Such photometric imaging is feasible.

The two technical papers published during the contract provide useful and basic information on the behavior of proximity focused ultraviolet photocathode image tubes and magnetically focused image tubes which can be utilized to affect image rotation electronically. This means of dynamic yaw correction in combination with time delay integration is very useful in extending the exposure time and thereby the sensitivity of the imaging system.

Both of the redesigned AFGL UV Imager systems have performed reliably in the field at AEDC and in Greenland. This is in part due to the Vic Baisley, AFGL/LIU engineering, whose skill and understanding of the equipment has proven invaluable in diagnosing problems and making the necessary field repairs in Greenland.

#### 11. REFERENCES

1. Spatial Frequency Response of Proximity Focused Image Tubes, Lowrance, J.L., Cope, A.D. and Stergis, C.R., *SPIE* 932, p.132, 1988.
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